

PROCESS AND SYSTEM FOR REMOVING CONTAMINANTS FROM A  
NATURAL GAS STREAM

FIELD OF THE INVENTION

The invention relates to a process for removing water and hydrocarbons from a natural gas stream.

BACKGROUND OF THE INVENTION

5       The term "natural gas" is applied to gas produced from underground accumulations of widely varying composition. The main constituent of natural gas is methane. Apart from methane, natural gas generally includes other hydrocarbons, nitrogen, carbon dioxide,  
10       sometimes a small proportion of hydrogen sulphide, and often water. Hydrocarbon constituents include ethane (C<sub>2</sub>), propane(C<sub>3</sub>), butane(C<sub>4</sub>), pentane(C<sub>5</sub>), hexane(C<sub>6</sub>), heptane(C<sub>7</sub>), etc. Hydrocarbons having 5 or more carbon atoms are generally referred to as C<sub>5</sub>+. Constituents of a  
15       natural gas stream other than methane will be referred to as contaminants in the specification and in the claims. The invention relates in particular to the removal of contaminants by partial condensation followed by gas/liquid separation, and contaminants that can be  
20       removed in this way are also sometimes referred to as condensables.

25       The lighter constituents, C<sub>1</sub> up to and including C<sub>4</sub>, are in gaseous phase at atmospheric temperatures and pressures. The heavier constituents, C<sub>5</sub>+, are in gaseous phase when at elevated temperatures during production from the subsurface and in liquid phase when the gas mixture has cooled down. Natural gas containing such heavier constituents is known as "wet gas" as distinct

from dry gas containing none or only a small proportion of liquid hydrocarbons.

5 The removal of contaminants, in particular water and hydrocarbons, from natural gas streams is important to prevent problems that can occur during their transportation. In the event that untreated natural gas is transported through pipeline systems the pressure loss, which is inevitable in pipeline systems, causes liquids to be formed as a result of condensation of water and/or hydrocarbons. Slugs of these liquids can cause problems, such as plugging of pipelines and distribution systems. In addition, liquid water can accelerate corrosion.

15 A useful parameter for indicating the water content of any gas is in terms of the dewpoint. The dewpoint is generally defined as the temperature to which a gas must be cooled (at constant water content) in order for it to become saturated with respect to water vapour (i.e. attain equilibrium with liquid water). For mixtures such as natural gas, instead of a dewpoint the cricondenbar (highest pressure at a given temperature at which a vapour-liquid equilibrium is present) or cricondentherm (highest temperature at a given pressure at which a vapour-liquid equilibrium is present) are used.

25 In order to prevent the formation of liquids in a natural gas stream, contaminants, in particular water and, if applicable, hydrocarbons should be removed in order to lower the cricondentherm of the natural gas stream. In the case of natural gas with a low content of hydrocarbons other than methane, or in the case when hydrocarbon liquid formation is allowable, only water removal is required. Generally, however, there is a need for the removal of both water and hydrocarbons, which are

30

more difficult to remove, from the natural gas,  
especially to achieve a certain desired cricondentherm.

A known process for the removal of water and  
hydrocarbons from a natural gas stream is for example  
described in the article "Solving storage problems" by  
T. Schulz, J. Rajani, D. Brands, Hydrocarbon Engineering  
June 2001, pages 55-60. In the known process, the natural  
gas stream is contacted with an adsorbent bed in order to  
remove the water and hydrocarbon contaminants. After some  
time on stream the adsorption bed needs to be  
regenerated, which time also depends on the desired  
quality of the purified gas stream leaving the adsorbent  
bed because of preferential adsorption of different types  
of contaminants.

Adsorption of components from a gas mixture through  
solid adsorbents is a thermal exothermic process. This  
process is generally reverted by applying heat to the  
adsorbent and adsorbate phase. If the heat applied is  
sufficient, the adsorbed components will leave the  
adsorbent internal surface and pores. To complete  
regeneration, the adsorbent is once again cooled to its  
initial temperature. This reversion of the adsorption  
process is called regeneration.

Therefore in total three adsorption beds are provided  
in the known process, one of them being in adsorption  
mode, one of them being regenerated by passing a  
slipstream of the untreated natural gas stream at an  
elevated temperature over the bed so that adsorbed  
contaminants are removed from the bed, and one of them  
being cooled by the slipstream after the bed was  
regenerated. The slipstream is first passed through the  
bed to be cooled, then heated, and passed through the bed  
to be regenerated. The slipstream takes up contaminants

that are removed from the adsorbent bed in regeneration mode. The contaminated slipstream is then passed through an air and water cooler, so that contaminants that condense at the temperature of water (above hydrate formation temperature) can be separated off as a liquid in a separator. The flash gas is recycled to the natural gas stream to be treated, upstream of adsorption bed in adsorption mode.

A problem in the use of adsorbent beds to remove water and/or hydrocarbons from a natural gas stream is that it is not always possible to achieve a sufficiently low cricondentherm of the resulting purified gas stream from the bed in adsorption mode. Therefore, there is a need for a process enabling the removal of contaminants, typically both water and hydrocarbons, from the natural gas, to achieve a certain desired cricondentherm.

#### SUMMARY OF THE INVENTION

Accordingly, the invention provides a process for removing contaminants from a natural gas stream, the process comprising the steps of:

- (a) contacting part of the natural gas stream as a first gas stream at an elevated temperature with a first adsorbent bed in regeneration mode, to remove contaminants present on the first adsorbent bed, and to obtain a second gas stream that is enriched in contaminants compared to the first gas stream;
- (b) submitting the second gas stream to a gas/liquid separation step comprising cooling the second gas stream to a temperature such that at least some contaminants begin to condense into a first liquid phase that is rich in contaminants, and separating the first liquid phase from the second gas stream to create a third gas stream;

wherein the gas/liquid separation step forms a first gas/liquid separation step, and wherein the process further comprises

5 (c) submitting the third gas stream to a second gas/liquid separation step to obtain a second liquid phase that is rich in contaminants, and a lean gas stream.

10 The process of the invention allows an advantageous and efficient treatment of the part of the natural gas stream (first gas stream) that is used for regeneration.

15 Regenerating the first adsorbent bed results in an increase in contaminants content of the second gas stream leaving the bed as compared to the first gas stream entering the bed. Although in this way the adsorbent bed can be regenerated, the regeneration gas now is of (far) worse quality than the original natural gas stream. This is a problem since it is generally desired to recycle the regeneration gas stream to an adsorbent bed in adsorption mode. In the prior art, this problem is solved by cooling  
20 the regeneration gas in an air and water cooler, so as to condense part of the contaminants into a liquid phase, and by separating the liquid phase from the regeneration gas.

25 Applicant has found that the quality of the regeneration gas stream obtained in this way is, at best, comparable to the quality of the original natural gas stream, in terms of the cricondentherm of the streams, and in terms of the water and hydrocarbon constituents contributing to the cricondentherm.

30 In particular, applicant has realized that it is beneficial to purify the regeneration gas further, by performing a second gas/liquid separation step wherein

further contaminants are condensed into a liquid and separated off phase so that a lean gas is obtained.

In this way actually a better quality of the regeneration gas can be obtained than the original natural gas stream. So the regeneration gas is first enriched in contaminants, and then contaminants are removed so that overall the contaminants level is decreased.

Suitably, another part of the natural gas stream is contacted with a second adsorbent bed in adsorption mode, to obtain a purified gas stream.

When the lean gas stream is then contacted with the second adsorbent bed, together with the other part of the natural gas stream, a purified gas stream can be obtained that is of better quality than what is obtainable with the known process, due to the better quality of the lean gas that is recycled from regeneration. It has been found that this is a very efficient way to improve the quality of the purified gas, just sufficiently to obtain required specifications in many practical situations, without having to modify other parts of the process such as the absorption step. The present invention moreover helps to minimize the fraction of the natural gas stream that has to be used for regeneration.

Suitably, the lean gas stream has a cricondenthem lower than that of the natural gas stream, preferably at least 10 °C lower, more preferably at least 15 °C lower, most preferably at least 20 °C lower.

In absolute terms, the lean gas stream suitably has a cricondenthem below 10 °C, preferably below 6 °C, more preferably below 0 °C, most preferably below -5 °C.

The purified gas stream obtained from the second adsorbent bed suitably has a cricondenthem below 10 °C,

preferably below 6 °C, more preferably below 0 °C, most preferably below -5 °C, or even below -10 °C.

The cooling in step (b) is suitably done against a temperature above water freezing temperature, in particular using a water cooler.

The temperature of the second adsorbent bed is suitably at ambient temperature, such as between 5 and 45 °C, preferably between 20 and 30 °C.

The temperature of the first adsorbent bed is suitably between 200 and 350 °C, preferably between 250 and 325 °C, more preferably between 275 and 310 °C such as 280 or 300 °C.

Step (c) comprises cooling the third gas stream to a temperature that is below a temperature at which contaminants in the third gas stream will begin to condense into a second liquid phase, and separating the second liquid phase from the third gas stream. Suitably the third gas stream is cooled to a temperature below the cooling temperature in step (b), preferably to a temperature below water freezing temperature (0 °C), more preferably to a temperature below -5 °C.

In a particularly advantageous embodiment of the process according to the invention, the second gas/liquid separation in step (c) is effected by means of an accelerated velocity inertia separator. Such a separator creates a fluid stream flowing at accelerated velocity and causes said fluid stream to cool to a temperature at which water and hydrocarbons will condense into a second liquid water/hydrocarbon phase. The accelerated velocity inertia separator is advantageously a supersonic inertia separator and the fluid stream flows at supersonic velocity. Further, a swirling motion can suitably be induced to the fluid stream flowing at supersonic

velocity, thereby causing the contaminants, in particular water and hydrocarbons, to flow to a radially outer section of a collecting zone in the stream.

Such a separator is advantageous as it is very  
5 efficient to remove contaminants that influence the cricondentherm, in particular water and hydrocarbons. Such a separator is as such known from US patent specification No. 6,280,502. Applicant has realized that  
10 is is particularly advantageous to use such a separator which causes a sizeable pressure drop, since in many cases there is some excess pressure of the natural gas stream as compared to the pressure used for adsorption. So the pressure drop in the regeneration branch is actually acceptable, and requires normally only moderate  
15 compression afterwards if the lean gas is also sent to the adsorption bed. Compression requirements are also limited since the fraction of the natural gas stream that is used for regeneration can be minimized, such as 40% or less, or preferably 30% or less of the total natural gas  
20 stream is used as first gas stream.

In an alternative embodiment, the cooling of the third gas stream is effected by refrigeration. In this case suitably a hydrate inhibitor, preferably methanol, is injected into the third gas stream prior to  
25 refrigeration.

Step (a) comprises suitably heating the first gas stream in a heating zone to obtain a heated first gas stream; and contacting the heated first gas stream with the first adsorbent bed in regeneration mode. Heating of  
30 the adsorbent bed to elevated temperature is in this way effected by the regeneration gas.



The first gas stream can be passed through a third adsorbent bed in cooling mode, prior to being contacted with the first adsorbent bed.

The invention further provides a system for removing  
5 contaminants from a natural gas stream, the system comprising:

- a first adsorption bed arranged to receive part of the natural gas stream as a first gas stream, and provided with a means for heating the first adsorbent  
10 bed, which first adsorption bed has an outlet for a second gas stream
- a cooler for cooling the second gas stream;
- a first gas/liquid separator for separating the cooled second gas stream into a first liquid phase and a  
15 third gas stream; and
- a second gas/liquid separator for separating the third gas stream into a second liquid phase and a lean gas stream.

The system suitably further comprises a second  
20 adsorbent bed arranged to receive another part of the natural gas stream at a temperature at which contaminants are adsorbed, and having an outlet for a purified gas stream. The second adsorbent bed can in particular be arranged to receive the lean gas stream together with the  
25 other part of the natural gas stream.

The first gas/liquid separator suitably comprises a cooler condensing liquid at a temperature above the freezing point of water, such as a water and/or air cooler, and wherein the second gas/liquid separator is  
30 arranged to separate contaminants that condense at a temperature lower than 0 °C.

The second gas/liquid separator can advantageously be an accelerated velocity inertia separator, preferably a supersonic inertia separator.

The second gas/liquid separator can also comprise a refrigerator.

The process and system according to the invention allows, in addition to the removal of water, the removal of hydrocarbons from the feed gas stream, resulting in a lower cricondentherm compared to the feed gas stream. In the process according to the invention, the extent of removal of water and hydrocarbons from the feed gas stream can be steered, thereby creating a fourth (lean) gas stream with a desired cricondentherm, even in cases where the composition of the feed gas stream is such that a lowering of the cricondentherm to a sufficiently low level could not have been achieved using other techniques such as the process using only adsorption.

#### DETAILED DESCRIPTION OF THE INVENTION

The composition of the natural gas stream can vary. Typically, the natural gas stream comprises water in concentrations in the range of from 0.01 to 4 mol%, preferably from 0.05 to 2 mol%. The concentration of C<sub>2</sub>, C<sub>3</sub> and C<sub>4</sub> hydrocarbons in the feed gas stream is typically in the range of from 0.4 to 4 mol%, in particular from 1.0 to 3 mol%. The concentration of C<sub>5</sub>+ hydrocarbons in the feed gas stream is typically in the range of from 0.05 to 5 mol%, in particular from 0.1 to 3 mol%, based on the feed gas stream.

Contacting part of the natural gas stream is contacted as a first gas stream at an elevated temperature with a first adsorbent bed in regeneration mode, to remove contaminants present on the first adsorbent bed. The elevated temperature is suitably

provided by heating the part of the feed gas stream in a heating zone to obtain a heated first gas stream.

Typically, the part of the feed gas stream heated in a heating zone is in the range of from 10 to 60%, preferably from 20 to 50%, more preferably 30% or less of the total feed gas stream. Generally, heating temperatures in the heating zone are in the range of from 150 to 450 °C, preferably from 200 to 400 °C, or from 250 to 350 °C.

The heated first gas stream is contacted with a first adsorbent bed, the first adsorbent bed being in the regeneration mode, to obtain a second gas stream. Adsorption of components from a gas mixture through solid adsorbents is a thermal exothermic process. This process can be reverted by applying heat to the adsorbent and adsorbate phase. If the heat applied is sufficient, the adsorbed components will leave the adsorbent internal surface and pores. To complete regeneration, the adsorbent is once again cooled to its initial temperature. This reversion of the adsorption process is called regeneration.

Reference herein to the first adsorption bed being in regeneration mode is to the first adsorption bed, comprising adsorbed contaminants, predominantly water and/or hydrocarbons, being subjected to conditions which will cause the adsorbed components to leave the adsorbent internal surface and pores and to be transferred to the heated gas stream.

In the first adsorbent bed, at least part of the adsorbed components are transferred from the first adsorbent bed to the heated first gas stream to obtain a second gas stream.

Preferably, the temperature at which the first adsorbent bed is subjected via the heated regeneration stream is in the range of from 200 to 350 °C, more preferably from 250 to 330 °C, to enable the regeneration of the adsorbent without causing thermal instability of the adsorbent.

The second gas stream obtained after step (b) is typically enriched in contaminants, typically in water and in C<sub>5</sub>+ hydrocarbons, compared to the heated first gas stream. Typically, the amount of water in the second gas stream is in the range of from 1.1 to 20 times, more typically from 2 to 10 times the amount of water in the total heated gas stream. Typically, the amount of C<sub>5</sub>+ hydrocarbons in the second gas stream is in the range of from 1.5 to 25 times, in particular from 3 to 15 times the amount of water in the total heated gas stream.

Generally, the pressure of the second gas stream is lower than the pressure of the heated first gas stream, typically 1 to 10 bar lower.

In step (b), the second gas stream is cooled to a temperature such that at least some water and some hydrocarbons will begin to condense into a first liquid water/hydrocarbon phase. The cooling temperature can be adjusted and depends on the temperature of the second gas stream. Typically cooling is done by means of an air and/or water cooler, and cooling temperatures are typical air or water temperatures, in particular above the freezing point of water, such as above the freezing the range of from 0 to + 10 °C.

Preferably, between 0.5% and 90% of the water and hydrocarbon contaminants will condense, more preferably between 1.0% and 80%, based on the total water and

hydrocarbon contaminants present in the gaseous phase in the gas stream.

Typically, the first liquid water/hydrocarbon phase comprises water and C<sub>5</sub>+ as the principal components.

5 Preferably, the liquid water/hydrocarbon phase comprises between 5 and 90 wt% water, more preferably between 10 and 80 wt%, most preferably between 15 and 50 wt%, based on the total water/hydrocarbon phase.

10 The first liquid water/hydrocarbon phase is separated from the second gas stream and discharged to create a third gas stream depleted of contaminants. The separation can for example be achieved using a gas/liquid separator, in particular a high pressure separation vessel. The third gas stream typically comprises water in the range  
15 of from 0.01 to 1 mol%, in particular from 0.05 to 5 mol%, more in particular 0.1 to 2 mol%, based on the third gas stream.

Typically, the third gas stream is enriched in hydrocarbon contaminants. Preferably, the third gas  
20 stream comprises C<sub>2</sub>+ hydrocarbon contaminants in the range of from 0.5 to 5 mol%, based on the total third gas stream.

In the second gas/liquid separation step (c), the third gas stream is suitably cooled to a temperature that  
25 is below a temperature at which water and hydrocarbons that are still present after the first separation step, will begin to condense into a second water/hydrocarbon phase.

In one preferred embodiment, the cooling in step (c)  
30 is achieved by leading the third gas stream through a conduit of an accelerated velocity inertia separator, thereby creating a fluid stream flowing at accelerated velocity. This fluid stream is then caused to cool to a

temperature that is below a temperature at which water and hydrocarbons will begin to condense into a second liquid water/hydrocarbon phase.

5 Because the use of an accelerated velocity inertia separator results in a considerable pressure drop, this embodiment is especially suitable in cases where the feed gas stream, and hence the third gas stream, has a relatively high pressure compared to the required pressure of the fourth gas stream (lean gas stream).

10 Typically, in cases where the pressure of the third gas stream is in the range of from 80 to 150 bar, preferably from 90 to 140 bar, the use of an accelerated velocity inertia separator is preferred.

15 Reference herein to an accelerated velocity inertia separator is to an apparatus wherein a fluid stream is induced to flow at accelerated velocity through a conduit, so as to decrease the temperature of the fluid in the conduit to below a temperature at which a selected component will condense into a second liquid  
20 water/hydrocarbon phase.

Preferably, the accelerated velocity inertia separator is a supersonic inertia separator wherein the velocity in the radially outer section and in the central part of the stream is supersonic. Suitable supersonic  
25 velocity inertia separators are described in US 6,280,502. The supersonic inertia separator causes the fluid stream to flow at supersonic velocity. This causes a rapid expansion, resulting in cooling of a compressible fluid stream. The cooling results in condensation of  
30 vapours to the extent that such cooling brings the temperature of the stream to a temperature below a point where components will condense to form a separate second water/hydrocarbon phase.

Suitably, the conduit is provided with swirl imparting means to impart a swirling motion to the stream of fluid flowing at accelerated velocity.

Preferably, a swirling motion is induced to the stream of fluid flowing at supersonic velocity, thereby causing the water and hydrocarbons to flow to a radially outer section of the regenerated gas stream.

Preferably, a wing placed in the supersonic flow region imparts the swirling motion. Reference herein to the supersonic flow region is to the part of the conduit of the supersonic velocity inertia separator wherein the fluid stream flows at supersonic velocity.

Preferably, a shock wave is created in the stream that is upstream of the radially outer section and downstream of the location where the swirling motion has been imparted.

Preferably, the shock wave is created by inducing the stream of fluid to flow through a diffuser. A diffuser may be a diverging volume, or a converging and a diverging volume.

It was found that the separation efficiency is significantly improved if collection of the condensed particles takes place after the shock wave, i.e. in subsonic flow rather than in supersonic flow. This is because the shock wave dissipates a substantial amount of kinetic energy of the stream and thereby strongly reduces the axial component of the fluid velocity while the tangential component (caused by the swirl imparting means) remains substantially unchanged. As a result the density of condensable components in the radially outer section is significantly higher than elsewhere in the conduit where the flow is supersonic. It is believed that this effect is caused by the strongly reduced axial fluid

velocity and thereby a reduced tendency of the particles to be entrained by a central "core" of the stream where the fluid flows at a higher axial velocity than nearer the wall of the conduit. Thus, in the subsonic flow regime the centrifugal forces acting on the condensed components are not to a great extent counter-acted by the entraining action of the central "core" of the stream, so that the condensed components are allowed to agglomerate in the radially outer section from which they are extracted.

In another preferred embodiment, the second gas/liquid separation step includes cooling by means of refrigeration. This embodiment is especially suitable in cases where the pressure of the feed gas stream, and hence also the pressure of the third gas stream, is relatively low compared to the required pressure of the fourth gas stream. Typically, in cases where the pressure of the third gas stream is in the range of from 10 to 100 bar, preferably from 30 to 80 bar, refrigeration as cooling means in step (e) is advantageous. To prevent the formation of hydrates, methanol is preferably added in the refrigeration step.

The second liquid water/hydrocarbon phase is separated from the third gas stream and discharged, to create a fourth gas stream. Typically, the second liquid water/hydrocarbon phase is enriched in C<sub>2</sub>+ components.

In the embodiment where an accelerated intertia separator is used, the second liquid water/hydrocarbon phase is suitably separated in a first outlet stream from a radially outer section of the third gas stream. Preferably, the remaining fourth gas stream is collected



in a second outlet stream from a central part of the third gas stream.

Typically, the fourth gas stream obtained after step (f) comprises between 0.001 and 4 mol% of total components selected from the group of C<sub>2</sub>, C<sub>3</sub> and C<sub>4</sub>, more typically between 0.01 and 3 mol%, most typically between 0.5 and 2 mol%, based on the total fourth gas stream.

In a preferred embodiment of the invention the process further comprises the step of contacting another part of the feed gas stream with a second adsorbent bed to remove in particular water and C<sub>5</sub>+ hydrocarbons. The resulting purified gas stream exiting the second adsorbent bed is typically depleted of water and of hydrocarbons with respect to the natural gas feed stream.

Preferably, the pressure of the other part of the feed gas stream is adjusted prior to being contacted with the second adsorbent bed, in order to conform to the operating pressure of the adsorbent bed. Typical operating pressures of the second adsorbent bed are between 40 and 120 bar, preferably between 70 to 100 bar.

Preferably, temperatures in the second adsorbent bed are in the range of from 5 to 50 °C, more preferably from 15 to 40 °C, most preferably from 20 to 30 °C. This enables sufficient removal of water and/or hydrocarbon contaminates without the need for excessive heating.

In the adsorbent bed, generally two zones, an equilibrium zone and a mass transfer zone, can be distinguished. In the equilibrium zone, the amount of adsorbed material of a component is in equilibrium with the partial pressure of the component in the feed. In the mass transfer zone, the adsorbent is actively adsorbing the component from the gas stream.

Suitable adsorbents in the first and in the second adsorbent bed are solids having a microscopic structure. The internal surface of such adsorbents is preferably between 100 and 2000 m<sup>2</sup>/g, more preferably between 500 and 1500 m<sup>2</sup>/g. The nature of the internal surface of the adsorbent in the adsorbent bed is such that water and C<sub>5</sub>+ hydrocarbons are adsorbed. Suitably, the internal surface of the adsorbent is polar. Suitable adsorbent materials include materials based on silica, silica gel, alumina or silica-alumina. Zeolite type adsorbents are preferred.

Generally, in the adsorbent bed water is preferentially adsorbed over hydrocarbons. C<sub>5</sub>+ hydrocarbons, hydrocarbons having 5 or more carbon atoms, will generally be preferentially adsorbed over lighter hydrocarbons such as C<sub>2</sub>, C<sub>3</sub> or C<sub>4</sub>. Typically, water is adsorbed to the extent that the resulting concentrations are in the range of from 0.001 to 0.5 mol%, in particular from 0.01 to 0.4 mol%, more in particular 0.05 to 0.2 mol%.

Typically, C<sub>5</sub>+ hydrocarbons are adsorbed to the extent that the resulting concentrations are in the range of from 0.01 to 1 mol%, in particular from 0.05 to 0.5 mol%.

It will be clear to the skilled person that the first and second adsorbent bed can alternatively be either in the adsorbent mode or in the regenerating mode, or optionally in a cooling mode. Although the preferred embodiment is described for two adsorbent beds, other embodiments wherein more than two adsorbent beds are used are comprised in the invention.

In another preferred embodiment, the process further comprises the step of contacting the fourth (lean) gas stream with the second adsorbent bed to further remove

water and C<sub>5</sub>+ hydrocarbons from the fourth gas stream, thereby obtaining a purified gas stream exiting the second adsorbent bed.

5 In this embodiment, it is possible to adjust the ratio between the two parts of the feed gas stream. By combining both gas streams to a purified gas stream exiting the second adsorbent bed, a purified gas stream having a certain desired cricondentherm can be achieved, which can be lower than what is achievable without the  
10 second gas/liquid separation step of the regeneration gas.

Preferably, the pressure of the fourth gas stream is adjusted prior to being contacted with the second adsorbent bed, for example using a compressor, in order  
15 to conform to the operating pressure of the adsorbent bed. More preferably, the pressure of the fourth gas stream is increased to a value of between 50% and 100% of the pressure of the feed gas stream, most preferably to a value of between 60% and 90% of the pressure of the feed  
20 gas stream.

The purified gas stream exiting the second adsorbent bed is further depleted of water and/or hydrocarbons and has a lower cricondentherm than the feed stream.

25 The invention will now be illustrated by means of schematic figure 1. Figure 1 represents a non-limiting example of a preferred embodiment of the invention. Part of a natural gas feed gas stream comprising methane, C<sub>2</sub>, C<sub>3</sub>, C<sub>4</sub>, C<sub>5</sub>+ hydrocarbons and water and having a starting pressure of 120 bara is led via line 1 to a valve (2) to  
30 decrease the pressure. The part of the feed gas stream with a decreased pressure is led via line (3) to a second adsorbent bed (4) comprising solid adsorbent material. In the second adsorbent bed, water and C<sub>5</sub>+ hydrocarbons are

adsorbed to create a purified gas stream depleted of water and C<sub>5</sub>+ hydrocarbons which is discharged from the first adsorbent bed via line (5). Another part of the feed gas stream is led via line (6) to a heating zone (7) where it is heated. The heated first gas stream is led via line (8) to a first adsorbent bed (9), the first adsorbent bed being in the regeneration mode, to create a second gas stream enriched in contaminants, in particular water and C<sub>5</sub>+ hydrocarbons. This second gas stream is led via line (10) to a cooling unit (11) which can be a water cooler, where it is cooled to a temperature such that water and hydrocarbons condense into a first liquid water/hydrocarbon phase. The cooled gas stream comprising the first liquid water/hydrocarbon phase is led via line (12) to a gas/liquid separator (13) where the first liquid water/hydrocarbon phase is separated and led from the gas/liquid separator via line (14). The resulting third gas stream is led from the gas/liquid separator to a further gas/liquid separator step via line (15). Reference numeral (16) can for example be an accelerated velocity inertia separator, or refrigerator together with a gas/liquid separation means. In either case, the third gas stream is caused to cool to a temperature that is below a temperature/pressure at which water and hydrocarbons condense into a second liquid water/hydrocarbon phase, the hydrocarbons in the water/hydrocarbon phase mostly comprising C<sub>3</sub>+ components. The second liquid water/hydrocarbon phase is separated from the fluid stream and is led from the cooling device via line (17). The resulting fourth gas stream, which is a lean gas stream enriched in C<sub>1</sub> compared to the feed gas stream, is led via line (18) to a compressor (19) where the pressure is increased. The pressurised fourth gas

stream is led via lines (20) and (3) to the second adsorbent bed.

The invention will further be illustrated by means of the following non-limiting examples:

5     Example 1 (Comparative example)

10     In the comparative example use is made of a line-up as shown in Figure 1, but without the separator means 16 and compressor 19. Part of a feed natural gas stream having a composition as shown in Table 1 is contacted with a second adsorbent bed, the second adsorbent bed being in the adsorbing mode. The pressure of the feed gas stream is 80 bara. The temperature of the feed gas is 25 °C. Another part (for example 30%) of the feed gas stream is heated to obtain a first heated gas stream. The  
15     heated first gas stream is contacted with a first adsorbent bed, the first adsorbent bed being in the regeneration mode, to create a second gas stream enriched in water and C<sub>5</sub>+ hydrocarbons. The second gas stream is cooled to a temperature such that water and hydrocarbons  
20     condense into a first liquid water/hydrocarbon phase. The first liquid water/hydrocarbon phase is separated. The composition of the resulting gas stream is given in Table 1. The resulting gas stream that is recycled from regeneration is of lower quality than the feed gas, in  
25     particular the methane content is lower, and C<sub>5</sub>-C<sub>7</sub> and water content are higher.

Table 1: Composition of gas streams in example 1  
(in mol%).

	Feed	2 <sup>nd</sup> gas stream	Resulting gas stream
C <sub>1</sub>	94.7138	93.5453	94.4675
C <sub>2</sub>	1.2536	1.2382	1.2361
C <sub>3</sub>	0.1144	0.1130	0.1099
N <sub>2</sub>	0.4981	0.4919	0.4981
CO <sub>2</sub>	2.8184	2.7836	2.7984
He	0.0001	0.0001	0.0001
iC <sub>4</sub>	0.0209	0.0206	0.0193
NC <sub>4</sub>	0.0308	0.0304	0.0278
NC <sub>5</sub>	0.1992	0.2642	0.2107
NC <sub>6</sub>	0.1494	0.5410	0.3306
NC <sub>7</sub>	0.1000	0.5464	0.2155
BNZN	0.0000	0.0004	0.0002
NC <sub>8</sub>	0.0200	0.0854	0.0185
TOLU	0.0000	0.0000	0.0000
NC <sub>9</sub>	0.0150	0.0563	0.0060
NC <sub>10</sub>	0.0080	0.0283	0.0014
H <sub>2</sub> O	0.0583	0.2549	0.0598
	100.0000	100.0000	100.0000

### Example 2

A feed gas having a composition as shown in Table 2 is subjected to a process based on example 1, but now according to the present invention as described in figure 1, the cooling device (16) being an accelerated inertia separator. The resulting composition of the 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> (lean) gas stream are given in Table 2.

Table 2: Composition of gas streams in example 2  
(in mol%).

	Feed	2 <sup>nd</sup> gas stream	3 <sup>rd</sup> gas stream	4 <sup>th</sup> gas stream
C <sub>1</sub>	94.7138	93.5640	94.3886	95.0137
C <sub>2</sub>	1.2536	1.2307	1.2282	1.2220
C <sub>3</sub>	0.1144	0.1106	0.1077	0.1035
N <sub>2</sub>	0.4981	0.4926	0.4982	0.5023
CO <sub>2</sub>	2.8184	2.7775	2.7902	2.7966
He	0.0001	0.0001	0.0001	0.0001
iC <sub>4</sub>	0.0209	0.0197	0.0185	0.0167
NC <sub>4</sub>	0.0308	0.0285	0.0262	0.0224
NC <sub>5</sub>	0.1992	0.2477	0.2003	0.1255
NC <sub>6</sub>	0.1494	0.7659	0.4811	0.1609
NC <sub>7</sub>	0.1000	0.4396	0.1814	0.0244
BNZN	0.0000	0.0004	0.0003	0.0001
NC <sub>8</sub>	0.0200	0.0607	0.0140	0.0007
TOLU	0.0000	0.0000	0.0000	0.0000
NC <sub>9</sub>	0.0150	0.0390	0.0045	0.0001
NC <sub>10</sub>	0.0080	0.0194	0.0010	0.0000
H <sub>2</sub> O	0.0583	0.2036	0.0598	0.0110
	100.0000	100.0000	100.0000	100.0000

It can be seen in this example that overall contaminants have been removed from the feed. The total methane content is higher as compared to the comparative example. The total hydrocarbon content other than methane is lower. The additional separation step is particularly effective in removing C<sub>3</sub>+ and water contaminants. The

biggest absolute changes are observed for C<sub>3</sub>-C<sub>7</sub>. Feeding this lean gas with low contaminant levels into the second adsorption bed in adsorption mode will improve the overall performance of the process. Suitably maximum 30% of the natural gas feed is used for regeneration. The significant reduction of water and hydrocarbon contaminants in this part leads to an improved adsorption performance in the second adsorbent bed, so that a purified feed with higher quality than in the comparative example, in particular lower cricondentherm, is obtained.

#### Example 3

A feed gas having a composition as shown in Table 3 is subjected to a process as described in figure 1, the cooling device (16) being a refrigerator, run at 80 bar and -7 °C. The resulting composition of the 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> (lean) gas stream are given in Table 3.



Table 3: Composition of gas streams in example 3 (in mol%).

	Feed	2 <sup>nd</sup> gas stream	3 <sup>rd</sup> gas stream	4 <sup>th</sup> gas stream
C <sub>1</sub>	94.7138	93.5373	94.4085	94.8961
C <sub>2</sub>	1.2536	1.2300	1.2272	1.2181
C <sub>3</sub>	0.1144	0.1107	0.1076	0.1038
N <sub>2</sub>	0.4981	0.4926	0.4985	0.5023
CO <sub>2</sub>	2.8184	2.7759	2.7892	2.7886
He	0.0001	0.0001	0.0001	0.0001
IC <sub>4</sub>	0.0209	0.0198	0.0185	0.0171
NC <sub>4</sub>	0.0308	0.0288	0.0263	0.0235
NC <sub>5</sub>	0.1992	0.2342	0.1868	0.1393
NC <sub>6</sub>	0.1494	0.7611	0.4655	0.2433
NC <sub>7</sub>	0.1000	0.4873	0.1929	0.0572
BNZN	0.0000	0.0005	0.0003	0.0001
NC <sub>8</sub>	0.0200	0.0623	0.0136	0.0019
TOLU	0.0000	0.0000	0.0000	0.0000
NC <sub>9</sub>	0.0150	0.0390	0.0042	0.0003
NC <sub>10</sub>	0.0080	0.0194	0.0010	0.0000
H <sub>2</sub> O	0.0583	0.2010	0.0598	0.0082
	100.0000	100.0000	100.0000	100.0000

Also in this example that the total methane content is higher as compared to the comparative example, be it somewhat lower than in example 2. Also the other contaminant species show similar trends.

#### Example 4

A feed gas having a composition as shown in Table 4 is subjected to a process as described in figure 1, the

cooling device (16) being a refrigerator, run at 80 bar and  $-7^{\circ}\text{C}$ . Methanol was added in sufficient quantities to prevent hydrate formation. The resulting composition of the 2<sup>nd</sup>, 3<sup>rd</sup> and 4<sup>th</sup> gas stream are given in Table 4.

Table 4: Composition of gas streams in example 4 (in mol%).

	Feed	2 <sup>nd</sup> gas stream	3 <sup>rd</sup> gas stream	4 <sup>th</sup> gas stream
C <sub>1</sub>	94.7138	93.6176	94.4937	94.9250
C <sub>2</sub>	1.2536	1.2315	1.2291	1.2213
C <sub>3</sub>	0.1144	0.1109	0.1079	0.1046
N <sub>2</sub>	0.4981	0.4930	0.4989	0.5022
CO <sub>2</sub>	2.8184	2.7787	2.7924	2.7920
He	0.0001	0.0001	0.0001	0.0001
iC <sub>4</sub>	0.0209	0.0198	0.0186	0.0174
NC <sub>4</sub>	0.0308	0.0289	0.0264	0.0239
NC <sub>5</sub>	0.1992	0.2239	0.1793	0.1382
NC <sub>6</sub>	0.1494	0.5504	0.3390	0.1884
NC <sub>7</sub>	0.1000	0.5815	0.2323	0.0755
BNZN	0.0000	0.0006	0.0004	0.0002
NC <sub>8</sub>	0.0200	0.0729	0.0161	0.0026
TOLU	0.0000	0.0000	0.0000	0.0000
NC <sub>9</sub>	0.0150	0.0451	0.0049	0.0003
NC <sub>10</sub>	0.0080	0.0224	0.0011	0.0000
H <sub>2</sub> O	0.0583	0.2226	0.0598	0.0082
	100.0000	100.0000	100.0000	100.0000

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The cricondentherm of the resulting fourth (lean) gas stream for examples 2 to 4 are given in Table 5. For the case of example 1, the cricondentherm of the resulting

5 gas stream (comparable with the fourth gas stream in the process according to the invention) is given. From Table 5 it is clear that all processes according to the invention (examples 2,3 and 4) result in a (fourth) gas stream having a lower cricondenthern compared to the gas stream obtained after a process according to the comparative example.

Table 5: Cricondenthern (in °C) of the fourth gas stream (in the case of example 1: of the resulting gas stream).

	Example 1	Example 2	Example 3	Example 4
Cricondenthern	+31	-6	+5.5	+6